Classification of Snow and Ice on Roads

Seiiti Kinosita and Eizi Akitaya

Snow on roads appears in many different types and changes ceaselessly by the action of traffic, snow removal work, and weather. Attention must be given to these changes in the study of snow removal and ice control operations and winter driving. Measurements were taken of density, hardness, temperature, and soil content; and micrographical observations were made in the winters of 1968-1969 and 1969-1970 on thin snow layers covering urban arterial roads in Hokkaido, Japan. Based on these data, the following classifications are proposed: new snow, composed of snowflakes; powder snow, composed of loose grains 0.05 to 0.3 mm in diameter and blown up by a passing car; granular snow, composed of loose grains 0.3 mm or larger in diameter, never blown up, and formed by thermal metamorphosis, mechanical mixing, or chemical treatment; packed snow, composed of a network texture of grains of 0.05 to 0.3 mm in diameter; ice crust, formed by freezing of wet packed snow; ice film, formed by freezing of meltwater film; and slush, formed by melting of snow and splashed by a passing car.

Snow layers on roads carrying traffic are usually thin; the thickness is ordinarily less than several centimeters. The snow changes ceaselessly by the action of traffic, snow removal work, and weather. It is important to understand the characteristics of the different types of snow that these changes produce.

Snow and ice were observed on urban arterial roads in Hokkaido, Japan, in the winters of 1968-1969 and 1969-1970. Measurements were taken of density, hardness, temperature, free water content, and soil content; micrographical observations were made of the textures. Based on these results, 7 types of snow and ice on roads are proposed: new snow, powder snow, granular snow, packed snow, ice crust, ice film, and slush.

Sometimes one type will exist in a single layer on roads, and at other times a combination of types will exist in layers. Changes from one type to another occur frequently and are caused by mechanical mixing, chemical treatment, or heat absorption. The heat is supplied from warm air, solar radiation, or car tires rotating at high speeds. Measurements were made of the tire temperatures.

OBSERVATION METHODS

Snow layers covering roads were cut vertically from the snow surface to the pavement; a cross section is shown in Figure 1. Measurements were taken of the following:

1. Density (ρ, g/cm^3)—If the snow was composed of loose grains, they were scraped together gently and placed in a box of 100 cm^3. The box was then weighed. If snow was compact, a lump was cut out of the layer with a small hatchet. The sides of the lump were shaved off with a carpenter's saw or plane to make it a rectangular cube, and then its dimension and weight were measured.
2. Hardness (H, kg/cm^2)—Kinosita's hardness gage (1) was used. The measured value H represents the resistance suffered by a body when it is dropped. The height of the fall and the depth of the hollow made on the snow surface were measured.
3. Temperature (T, deg C)—A thermistor was used.

4. Free Water Content (W_W, percent)—$W_W = a/\rho \times 100$, where a is the weight of free water contained in 1 cm^3 of snow. Yosida's combination calorimeter (2), which is composed of 2 containers (snow container and hot water container), was used.

5. Soil Content (W_S, percent)—$W_S = b/\rho \times 100$, where b is the weight of soil contained in 1 cm^3 of snow. The weight of a snow sample was measured before and after drying.

Micrographical observations were made in the cold room after snow samples had been brought in from observation points. Close-up photographs of grains of the snow and microphotographs of a thin section of the snow were taken. The thin section with a thickness of about 0.1 mm had been prepared by the aniline method (3).

The temperature of the tire of a running car was measured with an infrared radiation thermometer. A circular opening 10 cm in diameter was made in the center of the cover about the tire of a rear wheel of a Jeep (Mitsubishi J-30). The sensing head of this thermometer was directed to the top of the moving tire through the opening, and the measurement was made inside the moving car.

Questionnaires requesting information concerning weather conditions, snow removal work, snow features, and several other relevant quantities obtainable by simple measurement were sent beforehand to a number of snow removal departments (4). The questionnaires were filled in at designated observation points 3 times a day (early morning, daytime, and evening) for the duration of several days.

OBSERVATION POINTS

Observations were made at several points on the national highway near Sapporo City, where traffic has a density of 500 to 6,000 vehicles per day. One of the points was on a test road designed to investigate snow-melting effects by chemicals, where 50 to 80 g/cm^2 of calcium chlorides in pellet form were spread on the snow surface every snowy day after the snowplow had passed or when it started snowing. The following are the location of observation points: Route 5, Otaru, Kutchan, Inahotōge; Route 230, Ishiyama, Misumai, Nishikibashi (site of test road), Usubetsu, Nakayamatōge; and Route 231, Ishikari.

CROSS SECTION OF THE SNOW LAYER ON ROADS

A cross section of the snow on roads obtained at Usubetsu along Route 230 on January 28, 1969, is shown in the upper part of Figure 1. The snow is composed of 3 layers: powder snow, packed snow, and ice (each characteristic will be described later). The powder snow lies on top and is no more than 0.1 to 0.2 cm thick. The numbers on the first line below the cross section in Figure 1 indicate the thickness of total snow layers. The thickness is less than 4 cm at the portion of the road traveled by vehicles. The numbers within the parentheses indicate the thickness of ice adhering to the pavement. The numbers on the second and third lines indicate the density and the hardness of the packed snow respectively. They are larger than those of naturally

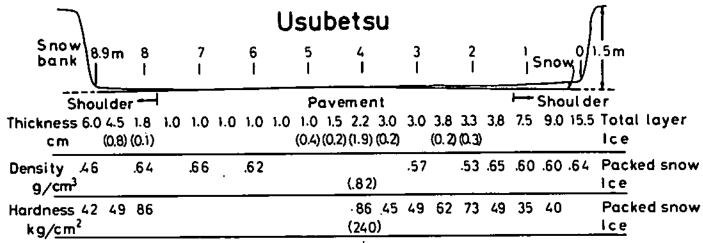

Figure 1. Cross section of snow obtained on Route 230 at Usubetsu on January 28, 1969, and composed of powder snow, packed snow, and ice. Air temperature was -4 C and snow temperature was -3 C.

TABLE 1

CLASSIFICATION OF SNOW AND ICE ON ROADS

Classification	Characteristics	Composition	Density (g/cm^3)	Hardness (kg/cm^2)
New snow	Exists immediately after a snowfall	Snowflakes (Fig. 6)	0.1	
Powder snow	Blown up by a passing car and drifts along the pavement surface (Fig. 2)	Loose grains 0.05 to 0.3 mm in diameter (Fig. 7)	0.27 to 0.41	
Granular snow	Never blown up and formed by thermal metamorphosis, mechanical mixing, and chemical treatment	Loose grains 0.3 mm or larger in diameter (Figs. 8 and 9)	0.28 to 0.50	
Packed snow	Formed by compaction of powder snow (Fig. 3)	Network texture of grains 0.05 to 0.3 mm in diameter (Fig. 10)	0.45 to 0.75	20 to 170
Ice crust	Formed by freezing of wet packed snow and more than 1 mm thick	Polycrystalline ice with air bubbles 0.1 to 0.5 mm in diameter (Fig. 13)	Over 0.75	90 to 300
Ice film	Formed by freezing of melt-water film and less than 1 mm thick	Polycrystalline ice with tiny air bubbles 0.01 to 0.1 mm in diameter (Figs. 11 and 12)		
Slush	Formed by melting of snow and splashed by a passing car (Fig. 5)	Loose grains 1 mm or larger in diameter (Fig. 14)	0.8 to 0.95	

deposited snow. The surface was hard enough to support vehicles and was a little slippery. The numbers within the parentheses on the second and third lines indicate the density and the hardness of the ice.

Several lumps were taken from the layers and carried to the cold room where they were observed micrographically and their soil contents and specific resistances of meltwater were measured. Soil contents of 2 packed snow samples were 0.07 and 0.15 percent. Specific resistance of one meltwater sample was $1.7 \times 10^4 \Omega$ cm.

Similar observations were made at other observation points.

Figure 2. Powder snow, blown up by a passing car.

Figure 3. Packed snow.

CLASSIFICATION

Based on the results of the observations obtained in the winters of 1968-1969 and 1969-1970, 7 types of snow and ice on roads are proposed. These are given in Table 1.

These types of snow and ice appear sometimes as a single layer and at other times as a combination of 2 or more layers, as shown in Figures 1 and 4. The following combinations have been observed (listed in order from top to bottom layer): (a) new snow, powder snow, granular snow, packed snow, and ice crust or ice film (more than 2 among these 5 types are stratified with upper ones always above lower ones); (b) ice film and packed snow; and (c) slush and ice crust or ice film.

CHANGE OF ONE TYPE INTO ANOTHER

New Snow to Powder Snow

When cars run over new snow, it changes into powder snow. Snow grains

Figure 4. Two stratified layers of powder snow and ice film. Ice film became visible by the trace of sliding tires.

Figure 5. Slush, splashed by a passing car.

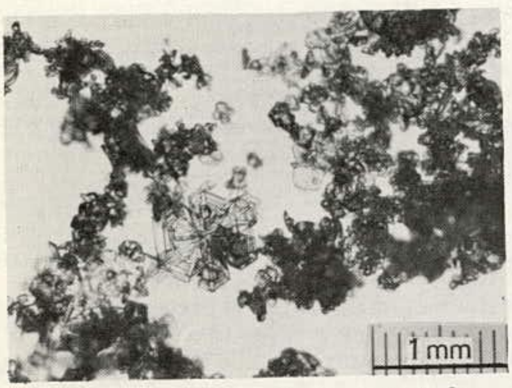

Figure 6. New snow (density 0.10 g/cm^3).

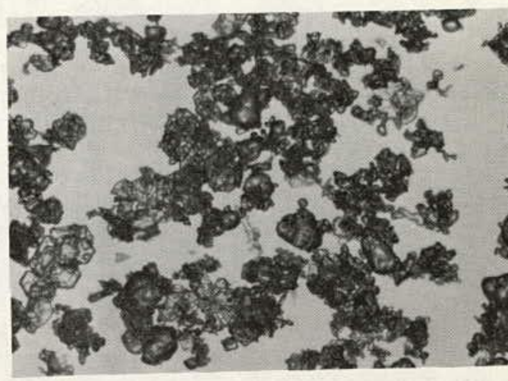

Figure 7. Powder snow (density 0.27 g/cm^3).

composing both types of snow are almost of the same dimension. However, some grains of the powder snow have a more rounded form, as shown in Figure 7, whereas snow flakes of the new snow are angular, as shown in Figure 6. The metamorphism is due to thermal effects; the heat from the tires of running cars is believed to account for it. The temperature of the tires is dependent on the air temperature, the running speed of the car, the character of the snow, the driving hours of the car, and weather conditions. When the car runs at a high speed, the temperature of the tires rises very often above 0 C, as given in Table 2.

TABLE 2

TEMPERATURE OF REAR WHEEL TIRES

Snow Type in Top Layer on Roads	Air Temperature (deg C)	Car Speed (km/hour)	Tire Temperature (deg C)
Powder snow	-10	60	0 to 2
		40	-4 to 0
	-4	40	2 to 3
Packed snow	-13	60	14
		50	10
		40	6
	-8	50	10 to 15
		40	9
Ice film	-1	40	7 to 13

Note: Measured in the running car after a driving time of more than 20 minutes.

Powder Snow to Granular Snow

When powder snow exists on an ice crust, an ice film, or the pavement during heavy traffic, the snow grains come closer and form larger grains but do not physically connect with one another. The cohesive force among small grains is due to the surface tension of meltwater films covering them, and the melt is caused by the heat from the tires. When the diameters of the grains exceed about 0.3 mm, the grains are never blown up by a passing car. Cohesive force decreases with the increasing of the diameter of the grains. If the diameter exceeds a critical value (about 1 mm), no more cohesion occurs. A photograph of granular snow is shown in Figure 8.

On the area where chemicals are applied to accelerate melting, powder snow changes into granular snow by the same mechanism except that the liquid film covering grains is formed owing to the lowering of the melting point. Traffic assists in mixing the chemical with the snow grains. Granular snow produced in this way is shown in the photograph in Figure 9. One grain is an assemblage of many tiny grains that have the same dimension as those of powder snow.

Powder Snow to Packed Snow

When powder snow is compacted by mechanical mixing such as the action of traffic or the snow removal work of a plow or grader, it changes into packed snow. Ice bonds are formed through sintering between snow grains in contact with each other (5). A network connection is thus produced, but it leaves the dimension of each snow grain unchanged, as shown in Figure 10.

Packed Snow to Granular Snow

When chemicals are scattered on the surface of packed snow, a part of the snow becomes liquid owing to the lowering of the melting point. The network connections in the packed snow are covered by a liquid film when packed snow melts to the extent that its free water content reaches about 20 percent. It becomes easy for bonds to be broken by mechanical action so that grains become separated to form loose grains. They then come together and form larger grains by the same mechanism that changes powder snow into granular snow.

Packed Snow to Ice Crust

When packed snow melts to the extent that its free water content exceeds the maximum capacity, the excess meltwater spreads downward and fills the air space in the snow mass contiguous to the pavement or the ice crust below (Fig. 13). If the water freezes again in cold weather, the snow changes into ice crust. The ice crust becomes thick by repetitive melting and freezing processes.

Formation of Ice Film

Ice films are formed by the freezing of meltwater film. The meltwater film appears very often on the pavement and sometimes on the top of the packed snow. The

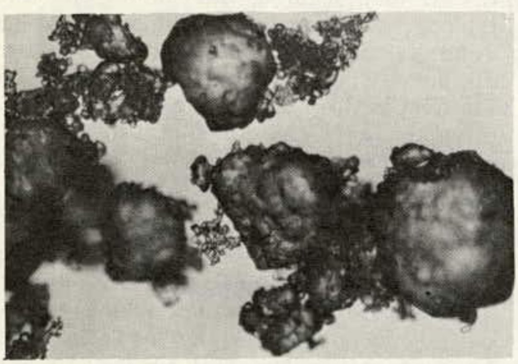

Figure 8. Granular snow (density 0.46 g/cm^3) formed by mechanical mixing.

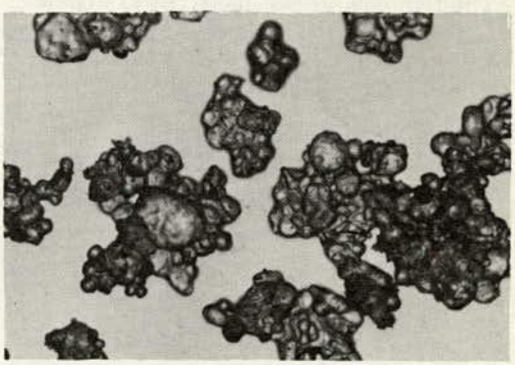

Figure 9. Granular snow (density 0.41 g/cm^3) formed by chemical treatment.

Figure 10. Packed snow (density 0.60 g/cm^3), thin section.

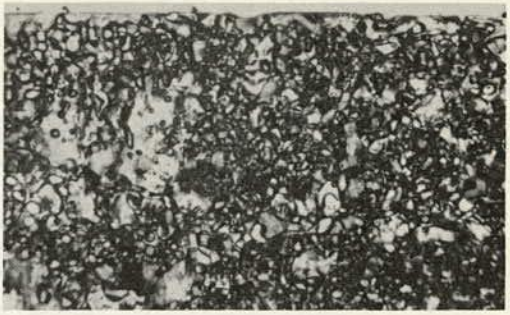

Figure 11. Vertical section of packed snow showing the presence of ice film at the top, thin section.

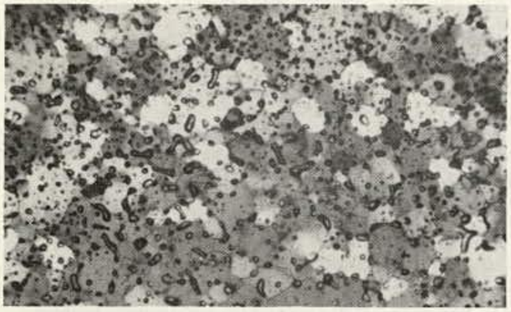

Figure 12. Surface view of ice film covering packed snow taken by polarized light, thin section.

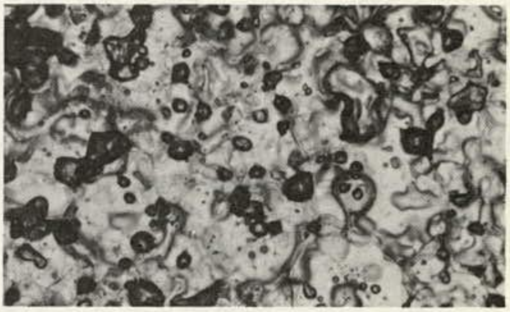

Figure 13. Ice crust (density 0.85 g/cm^3), thin section.

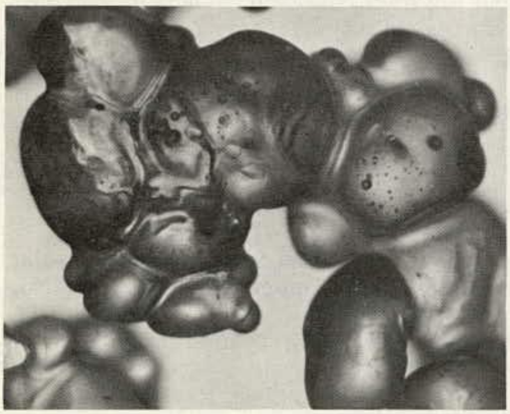

Figure 14. Slush (density 0.92 g/cm^3, dry density 0.60 g/cm^3).

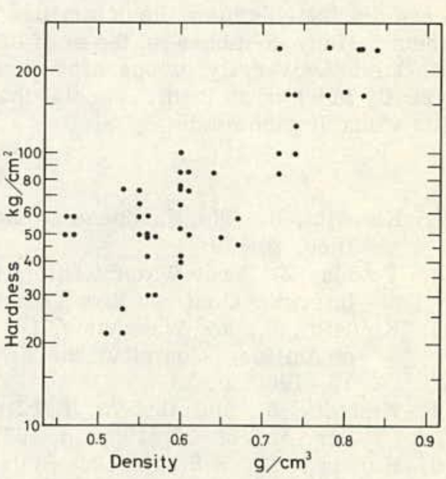

Figure 15. Relationship between hardness and density of dry packed snow.

presence of the former and the microtexture of the latter are shown in Figure 4 and Figures 11 and 12 respectively. Each type of snow and ice can form by the heat supplied from warm air, solar radiation, and tires.

Formation of Slush

When snow melts into water, the mixture of snow and water is splashed by a passing car, as shown in Figure 5. This type of snow, called slush, is composed of loose grains larger than 1 mm in diameter, as shown in Figure 14. According to the observations, the density ranged from 0.8 to 0.95 g/cm^3, the dry density from 0.45 to 0.6 g/cm^3, and the free water content from 30 to 50 percent.

RELATION BETWEEN HARDNESS AND DENSITY OF PACKED SNOW

In the suburbs, packed snow is predominant on roads (Fig. 3). Both the hardness and the density range widely as shown by the data in Figure 15. The relation between them is approximately given by

$$H = c\,\rho^4$$

where c, the constant obtained from the relation, ranges from 400 to 600. For naturally deposited snow, the value of c is approximately 100 in this relationship, ρ ranges from 0.1 to 0.4 g/cm^3, and the temperature is below 0 C (1).

TRAFFIC PROBLEMS DUE TO SNOW

The important traffic problems due to snow on roads are the decrease of visibility, the difficulty of snow removal work, and the slippery condition of the road surface. Powder snow remains in the air for a long time after a car has passed by and blown it up, making visibility poor (Fig. 2). Drivers of following cars have trouble seeing the direction of the road. Efficiency of snow-removal work changes with the hardness and the density of snow and ice, in particular for packed snow and ice crust. Ice film makes the road surface very slippery, as the traces of sliding tires in Figure 4 show. The relationships of these problems to snow and ice on roads will be the subject of future research.

ACKNOWLEDGMENTS

Planned by the Committee on Research of Snow on Roads, Japan Construction Mechanization Association, under the chairmanship of Dr. Ishihara, this study has been discussed among the committee members. The authors express their thanks to them. Many members on the staff of the Institute of Low Temperature Science, Hokkaido University, cooperated in carrying out the field research. The authors are greatly indebted to them. Special thanks are expressed to Professor Z. Yosida for his valuable comments.

REFERENCES

1. Kinosita, S. The Hardness of Snow. Low Temperature Science, Ser. A, Vol. 19, 1960, p. 119.
2. Yosida, Z. Free Water Content of Wet Snow. In Physics of Snow and Ice, Internat. Conf. on Low Temperature Science, Vol. 1, 1967, p. 773.
3. Kinosita, S., and Wakahama, G. Thin Sections of Deposited Snow Made by the Use of Aniline. Contributions From the Institute of Low Temperature Science, No. 15, 1960, p. 35.
4. Kinosita, S., and Akitaya, E. Snow and Ice on Roads. Low Temperature Science, Ser. A, Vol. 27, 1969, p. 163.
5. Kuroiwa, D. A Study of Ice Sintering. U.S. Army Cold Regions Research and Eng. Laboratory, Research Report 86, 1962.

Informal Discussion

M. E. Volz

Is this the temperature of the driving tires that you are measuring? Is there a differential between it and the tire that is rotating freely? Is there a direct relationship between speed, weight, tire pressure, and so on, and is it a direct ratio, something that you can compute or something that you got by observation and for which you have no formula? I am interested from the airplane pilot's viewpoint rather than from the viewpoint of a driver of a highway vehicle. Can we determine what the temperature will be in an airplane tire, for example, that is being driven over this ice-rubber interface, if you would like to call it that? Can you compute what the tire temperature will be, or was this just an observed temperature?

Kinosita

We measured the driving tire's temperature. We believe that there is a direct relationship between the speed, weight, tire pressure, and snow type and the driving tire's temperature; but we have not yet found any formula for it. We have never measured the temperature of a driving airplane tire on a snow surface, but you may use an infrared radiation thermometer to determine it.

Ambrose Poulin

What accuracy do you think you have in the measurement of tire temperature? Is it within ±5 deg?

Kinosita

It is within ±1 C.

Poulin

Do you have auxiliary measurements by other methods to determine the accuracy of your radiometric temperatures?

Kinosita

We measured the tire's temperature just after stopping the car with an infrared radiation thermometer and a thermistor. Both measurements gave the same value with the accuracy of ±1 C. We determined the accuracy of our radiometric temperature by measuring the surface temperature of the mixture of ice and water, which is just 0 C.

Volz

I have observed that when a pilot taxis an airplane or drives a car through new snow, mechanical work is done on the snow by the vehicle. It takes additional power to move the vehicle through the snow. Comparatively speaking, is the increase in tire temperature more important than the mechanical work that the vehicle does on the snow as far as melting is concerned?

Kinosita

Mechanical mixing is more important.

Volz

Does the mechanical mixing process increase the temperature?

Kinosita

Yes.

Peter Schaerer

Have you any practical experience with the suggested snow classification system? In order to determine the various classes of snow, it appears to be necessary to make an observation of the crystal shape. Can the man on the road, e.g., the maintenance foreman, do this, or can only an expert scientist classify the snow?

Kinosita

Our classification system is just a suggestion for further use. The observation of the crystal shape may be helpful, but it is not necessary for practical use.

A. G. Clary

Have your operating people made use of this system?

Kinosita

Yes.

Schaerer

Has this worked out?

Kinosita

Yes.

Clary

Has it worked out very well? Did they understand the procedure very well?

Kinosita

The maintenance foremen to whom we explained the procedure understood it very well.